A like-sign dimuon charge asymmetry at Tevatron induced by the anomalous top quark couplings

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We show that the recently measured 3.9 σ deviations of the charge asymmetry of like-sign dimuon events from the standard model prediction by the D0 collaboration at Tevatron can be explained by introducing the anomalous right-handed top quark couplings. Combined analysis with the $B_s - \bar{B}_s$, $B_d - \bar{B}_d$ mixings, $B \to X_s \gamma$ decays and the time-dependent CP asymmetry in $B \to \phi K$ decays has been performed. The anomalous tsW couplings are preferred to explain the dimuon charge asymmetry by other CP violating observables.

I. INTRODUCTION

Recently the D0 collaboration has measured the CP violating like-sign dimuon charge asymmetry for b hadrons, defined as

$$A^b_{sl} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}, \tag{1}$$

of which value is reported to be [1]

$$A^b_{sl} = (-0.957 \pm 0.172 \text{ (stat.)} \pm 0.093 \text{ (syst.)})\%, \tag{2}$$

in an integrated luminosity of 9.0 fb^{-1} of $p\bar{p}$ data at $\sqrt{s} = 1.96$ TeV at Tevatron. In the definition of Eq. (1), N_b^{++} and N_b^{--} are the number of events where two b hadrons semileptonically decay into muons with charges of the same sign. Since the b quarks are produced as $b\bar{b}$ pairs from $p\bar{p}$ collisions at Tevatron, the like-sign dimuon events arises from a direct semileptonic decay of one of b hadrons and a semileptonic decay of the other b hadron following the $B^0 - \bar{B}^0$ oscillation. In the standard model (SM), the source of the CP violation in the neutral B^0_q system is the phase of the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements involved in the box diagram. The D0 measurement of Eq. (2) shows a deviation of 3.9 σ from the SM prediction $A^b_{sl} = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$. The measured value of Eq. (2) is improved again by more data as more data is analyzed. If the deviation is confirmed with other experiments, it indicates the existence of the new physics beyond the SM. Many works are devoted to explanation of the D0 dimuon asymmetry in and beyond the SM [2].

Although the charged currents are purely left-handed in the SM, the existence of right-handed charged currents is predicted in many new physics models beyond the SM. For instance, the variant $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R \times \mathrm{U}(1)$ model [3] and a dynamical electroweak symmetry breaking model [4] predicts additional right-handed currents and some modification of the left-handed currents. In this work, we study the effects of the anomalous right-handed top quark couplings on the D0 like-sign dimuon charge asymmetry. We introduce additional right-handed top quark couplings without specifying the underlying model and assume no effects of new particles and additional neutral currents interactions. Impacts of the anomalous top quark couplings have been studied in flavour physics and at colliders [5–7]. Here, we show that the measurement of the A^b_{sl} can be explained by both of the anomalous tsW and tbW couplings, with accommodation of present data of $\mathrm{Br}(B \to X_s\gamma)$, ΔM_s, ΔM_d and CP asymmetry in $B \to \phi K$ decays at 2-σ level.

This paper is organized as follows. In section II, we present the formalism for the dimuon charge asymmetry and neutral B meson system. In section III, we present the contribution of the anomalous top quark couplings to $B \to X_s\gamma$, $B - \bar{B}$ mixings, and $B \to \phi K$ decays to obtain the possible parameter sets. In section IV, we discuss the dimuon charge symmetry with the anomalous top quark couplings and future experiments. Finally we conclude in section V.

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II. DIMUON CHARGE ASYMMETRY IN THE NEUTRAL B MESON SYSTEM

Since the like-sign dimuon events following $b\bar{b}$ production arise through the $B-\bar{B}$ oscillation, the dimuon charge asymmetry can be described in terms of the parameters of the $B-\bar{B}$ mixings. The neutral B meson system is described by the Schrödinger equation

$$i\frac{d}{dt}\begin{pmatrix} B_q(t) \\ \bar{B}_q(t) \end{pmatrix} = \left(M - \frac{i}{2}\Gamma\right)\begin{pmatrix} B_q(t) \\ \bar{B}_q(t) \end{pmatrix}, \tag{3}$$

where M is the mass matrix and Γ the decay matrix with $q = d, s$. The $\Delta B = 2$ transition amplitudes

$$\langle B_q^0 | \mathcal{H}_{\rm eff}^{\Delta B=2} | \bar{B}_q^0 \rangle = M_{12}^q, \tag{4}$$

leads to the mass difference between the heavy and the light states of B meson,

$$\Delta M_q \equiv M_H^q - M_L^q = 2|M_{12}^q|, \tag{5}$$

where $M_H^{B_q}$ and $M_L^{B_q}$ are the mass eigenvalues for the heavy and the light eigenstates respectively. The total decay width difference of the mass eigenstates is defined by

$$\Delta\Gamma_q \equiv \Gamma_L^q - \Gamma_H^q = 2|\Gamma_{12}^q|\cos\phi_q, \tag{6}$$

where the decay widths Γ_L and Γ_H are corresponding to the physical eigenstates B_L and B_H respectively and the CP phase is $\phi_q \equiv \arg(-M_{12}^q/\Gamma_{12}^q)$.

The like-sign dimuon events consist of a right-sign (RS) process and a wrong-sign (WS) process,

$$A_{sl}^b \equiv \frac{\Gamma(b\bar{b} \to \mu^+\mu^+ X) - \Gamma(b\bar{b} \to \mu^-\mu^- X)}{\Gamma(b\bar{b} \to \mu^+\mu^+ X) + \Gamma(b\bar{b} \to \mu^-\mu^- X)} = \frac{\Gamma_{RS}^+\Gamma_{WS}^+ - \Gamma_{RS}^-\Gamma_{WS}^-}{\Gamma_{RS}^+\Gamma_{WS}^+ + \Gamma_{RS}^-\Gamma_{WS}^-}, \tag{7}$$

in which Γ_{RS} denotes the direct semileptonic decay rate in the right-sign process and Γ_{WS} the decay in the wrong-sign process implying the semileptonic decay rate of the $B_q^0(\bar{B}_q^0)$ meson following $B_q^0 - \bar{B}_q^0$ oscillation. The dimuon asymmetry implies the CP violation in the B system.

The asymmetry of dimuon events is derived from the charge asymmetry of semileptonic decays of neutral B_q^0 mesons, a_{sl}^q defined as

$$a_{sl}^q \equiv \frac{\Gamma(\bar{B}_q^0(t) \to \mu^+ X) - \Gamma(B_q^0(t) \to \mu^- X)}{\Gamma(\bar{B}_q^0(t) \to \mu^+ X) + \Gamma(B_q^0(t) \to \mu^- X)}. \tag{8}$$

At Tevatron experiment, both decays of B_d and B_s mesons contribute to the asymmetry. Assuming that $\Gamma(B_d^0 \to \mu^+ X) = \Gamma(B_s^0 \to \mu^+ X)$ to a very good approximation, the like-sign dimuon charge asymmetry can be expressed in terms of a_{sl}^q as [9]

$$A_{sl}^b = \frac{1}{f_d Z_d + f_s Z_s}\left(f_d Z_d a_{sl}^d + f_s Z_s a_{sl}^s\right) \tag{9}$$

where f_q are the production fractions of B_q mesons, and $Z_q = 1/(1-y_q^2) - 1/(1+x_q^2)$ with $y_q = \Delta\Gamma_q/(2\Gamma_q)$, $x_q = \Delta M_q/\Gamma_q$. These parameters are measured to be $f_d = 0.323 \pm 0.037$, $f_s = 0.118 \pm 0.015$, $x_d = 0.774 \pm 0.008$, $x_s = 26.2 \pm 0.5$, and $y_d = 0$, $y_s = 0.046 \pm 0.027$ [10]. With these values, Eq. (10) is rewritten by

$$A_{sl}^b = (0.506 \pm 0.043)a_{sl}^d + (0.494 \pm 0.043)a_{sl}^s. \tag{10}$$

The charge asymmetry for wrong charge semileptonic decay in Eq. (9) is expressed as

$$a_{sl}^q = \frac{|\Gamma_{12}^q|}{|M_{12}^q|}\sin\phi_q = \frac{\Delta\Gamma_q}{\Delta M_q}\tan\phi_q, \tag{11}$$

of which the SM predictions are given by [25]

$$\begin{aligned} a_{sl}^d &= (-4.8^{+1.0}_{-1.2}) \times 10^{-4}, \\ a_{sl}^s &= (2.1 \pm 0.6) \times 10^{-5}. \end{aligned} \tag{12}$$

In the SM, $\Delta\Gamma_d/\Gamma_d$ is less than 1%, while $\Delta\Gamma_s/\Gamma_s \sim 10\%$ is rather large. The decay matrix elements Γ_{12}^q is obtained from the tree level decays $b \to c\bar{c}q$. Since the anomalous top couplings affects Γ_{12}^q through loops only, we ignore the new physics effects on Γ_{12}^q in this work.

III. ANOMALOUS TOP QUARK COUPLINGS AND B PHYSICS

In this paper, we work with an effective Lagrangian in a model independent way to parameterize the new physics effects. After fixing the phases of quarks so that $V_{tq}^{\rm SM}$ are the CKM matrix elements of the SM, we introduce the new Wtq couplings g_L^q and g_R^q to redefine the effective CKM matrix elements and right-handed couplings:

$$\begin{aligned}\mathcal{L} &= -\frac{g}{\sqrt{2}}\sum_{q=s,b} V_{tq}^{\rm SM}\ \left(\bar{t}\gamma^\mu P_L q W_\mu^+ + \bar{t}\gamma^\mu(g_L^q P_L + g_R^q P_R) q W_\mu^+\right) + H.c., \\ &= -\frac{g}{\sqrt{2}}\sum_{q=s,b} V_{tq}^{\rm eff}\ \bar{t}\gamma^\mu (P_L + \xi_q P_R) q W_\mu^+ + H.c.,\end{aligned} \tag{13}$$

where $V_{tq}^{\rm eff} = V_{tq}^{\rm SM}(1+g_L^q)$, and $V_{tq}^{\rm eff}\xi_q = V_{tq}^{\rm SM} g_R^q$. Since we set g_L^q and g_R^q to be complex, $V_{tq}^{\rm eff}$ and ξ_q involve new phases and will predict new CP violating processes in B physics. For simplicity, we assume that either one of anomalous tsW or tbW couplings is nonzero in this analysis. Then other CKM matrix elements are same as those in the SM and the phase of quarks are fixed with them.

The matrix elements of the third row of the CKM matrix are not directly measured yet, but just indirectly constrained by loop-induced processes and the unitarity of the CKM matrix. In our framework, the constraints should be applied to effective CKM matrix elements $V_{tq}^{\rm eff}$ instead of $V_{tq}^{\rm SM}$. The additional $V_{tq}^{\rm eff}\xi_q$ terms measure the anomalous right-handed top couplings. Effects on $W\bar{t}d$ coupling are ignored here due to the smallness of V_{td}.

A. $B \to X_s\gamma$ decays

Contributions of the right-handed top quark couplings to the penguin diagram for $b \to s$ transition are enhanced by the factor of m_t/m_b. Thus the radiative $B \to X_s\gamma$ decays are sensitive to the anomalous right-handed $W\bar{t}b$ and $W\bar{t}s$ couplings and provides strong constraints on them.

The $\Delta B = 1$ effective Hamiltonian for $B \to X_s\gamma$ process with the right-handed couplings is given by

$$\mathcal{H}_{eff}^{\Delta B=1} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{8} \left(C_i(\mu) O_i(\mu) + C_i'(\mu) O_i'(\mu)\right), \tag{14}$$

where the dimension 6 operators O_i are given in the Ref. [16], and O_i' are their chiral conjugate operators. The SM Wilson coefficients are shifted by $C_7(m_W) = F(x_t) + \xi_b(m_t/m_b)F_R(x_t)$ and $C_8(m_W) = G(x_t) + \xi_b(m_t/m_b)G_R(x_t)$ while the new Wilson coefficients are formed as $C_7'(m_W) = \xi_s(m_t/m_b)F_R(x_t)$ and $C_8'(m_W) = \xi_s(m_t/m_b)G_R(x_t)$ in the leading order of ξ_q. The Inami-Lim loop functions $F(x)$ and $G(x)$ are given by in Ref. [16, 17] and the new loop functions $F_R(x)$ and $G_R(x)$ can be found in Ref. [5, 6, 18].

The branching ratio of the $B \to X_s\gamma$ decays including ξ_s and ξ_b effects is given by

$$\begin{aligned}{\rm Br}(B \to X_s\gamma) &= {\rm Br}^{\rm SM}(B \to X_s\gamma)\left(\frac{|V_{ts}^{\rm eff\,*} V_{tb}^{\rm eff}|}{0.0404}\right)^2 \left[1 + Re(\xi_b)\frac{m_t}{m_b}\left(0.68\frac{F_R(x_t)}{F(x_t)} + 0.07\frac{G_R(x_t)}{G(x_t)}\right)\right. \\ &\left. + (|\xi_b|^2 + |\xi_s|^2)\frac{m_t^2}{m_b^2}\left(0.112\frac{F_R^2(x_t)}{F^2(x_t)} + 0.002\frac{G_R^2(x_t)}{G^2(x_t)} + 0.025\frac{F_R(x_t)G_R(x_t)}{F(x_t)G(x_t)}\right)\right],\end{aligned} \tag{15}$$

where the numerical values are obtained by the RG evolution in Ref. [19]. The SM prediction of the branching ratio is given by [20] ${\rm Br}(B \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$ and the current world average value of the measured branching ratio given by [21] ${\rm Br}(B \to X_s\gamma) = (3.55 \pm 0.24^{+0.09}_{-0.10} \pm 0.03) \times 10^{-4}$ with the photon energy cut $E_\gamma > 1.6$ GeV.

B. $B - \bar{B}$ mixings

The transition amplitude M_{12}^q for $B_q - \bar{B}_q$ mixing is obtained from the box diagrams in the SM. In our model, the top quark couplings in the box diagram is modified to include the right-handed couplings. Since the loop integral including the odd number of right-handed couplings vanishes, the leading contribution of ξ_q to M_{12} is of quadratic order. We write $M_{12}^{s,d}$ as

$$M_{12}^s = M_{12}^{s,SM}\left(\frac{V_{ts}^{\rm eff\,*} V_{tb}^{\rm eff}}{0.0404}\right)^2 \left(1 + \frac{S_3(x_t)}{S_0(x_t)}\left(\frac{\xi_s^2}{4}\frac{\langle \bar{B}_s^0|(\bar{b}P_R s)(\bar{b}P_R s)|B_s^0\rangle}{\langle \bar{B}_s^0|(\bar{b}\gamma^\mu P_L s)(\bar{b}\gamma_\mu P_L s)|B_s^0\rangle}\right.\right.$$

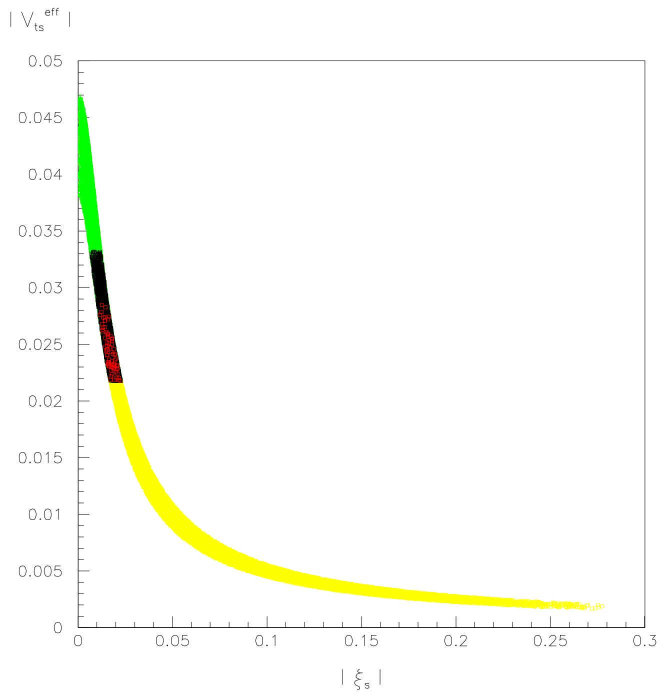

FIG. 1: Allowed parameters ($|\xi_s|, |V_{ts}^{\rm eff}|$) under the B physics constraints and D0 dimuon asymmetry. The whole band of the green (grey) + black + yellow (light grey) regions is allowed by Br($B \to X_s\gamma$) only. The green (grey) + black regions are allowed by Br($B \to X_s\gamma$) and ΔM_s. The black region is allowed by both constraints of Br($B \to X_s\gamma$) and ΔM_s, and satisfies A_{sl}^b measured by D0. The red (dark grey) dots denote points additionally allowed by CP asymmetries in $B \to \phi K$ decays. The confidence level is at 95 % C.L..

$$+\frac{\xi_b^*\xi_s}{2}\frac{\langle \bar{B}_s^0|(\bar{b}P_Ls)(\bar{b}P_Rs)|B_s^0\rangle}{\langle \bar{B}_s^0|(\bar{b}\gamma^\mu P_Ls)(\bar{b}\gamma_\mu P_Ls)|B_s^0\rangle} + \frac{{\xi_b^*}^2}{4}\frac{\langle \bar{B}_s^0|(\bar{b}P_Ls)(\bar{b}P_Ls)|B_s^0\rangle}{\langle \bar{B}_s^0|(\bar{b}\gamma^\mu P_Ls)(\bar{b}\gamma_\mu P_Ls)|B_s^0\rangle}\Bigg)\Bigg), \tag{16}$$

and

$$M_{12}^d = M_{12}^{d,SM}\left(V_{tb}^{\rm eff}\right)^2\left(1 + \frac{S_3(x_t)}{S_0(x_t)}\frac{{\xi_b^*}^2}{4}\frac{\langle B_d^0|(\bar{b}P_Ld)(\bar{b}P_Ld)|\bar{B}_d^0\rangle}{\langle B_d^0|(\bar{b}\gamma^\mu P_Ld)(\bar{b}\gamma_\mu P_Ld)|\bar{B}_d^0\rangle}\right), \tag{17}$$

where the Inami-Lim loop functions for new box diagrams are given by

$$S_3(x) = 4x^2\left(\frac{2}{(1-x)^2} + \frac{1+x}{(1-x)^3}\log x\right), \tag{18}$$

and the SM loop function $S_0(x)$ can be found elsewhere [16, 17]. The hadronic matrix elements for the four quark operators are parameterized by [12]

$$\begin{aligned}
\langle \bar{B}_q^0|(\bar{b}\gamma^\mu P_Lq)(\bar{b}\gamma_\mu P_Lq)|B_q^0\rangle &= \frac{8}{3}f_{B_q}^2\hat{B}_{B_q}m_{B_q}^2, \\
\langle \bar{B}_q^0|(\bar{b}P_Lq)(\bar{b}P_Lq)|B_q^0\rangle &= \langle \bar{B}_q^0|(\bar{b}P_Rq)(\bar{b}P_Rq)|B_q^0\rangle = -\frac{5}{3}f_{B_q}^2\hat{B}_{B_q}m_{B_q}^2\left(\frac{m_{B_q}}{m_b+m_q}\right)^2, \\
\langle \bar{B}_q^0|(\bar{b}P_Lq)(\bar{b}P_Rq)|B_q^0\rangle &= \frac{7}{3}f_{B_q}^2m_{B_q}^2\frac{m_q}{m_b},
\end{aligned} \tag{19}$$

where $\hat{B}_{B_q}$ is the Bag parameter and $f_{B_q}^2$ the decay constant.

The SM predictions of the mass differences are $\Delta M_d = 0.53 \pm 0.02$ ps^{-1} and $\Delta M_s = 19.30 \pm 6.74 \pm 0.07$ ps^{-1} [25]. and the measurements are $\Delta M_d = 0.509 \pm 0.006$ ps^{-1} [21] and $\Delta M_s = 17.77 \pm 0.10 \pm 0.07$ ps^{-1} [25].

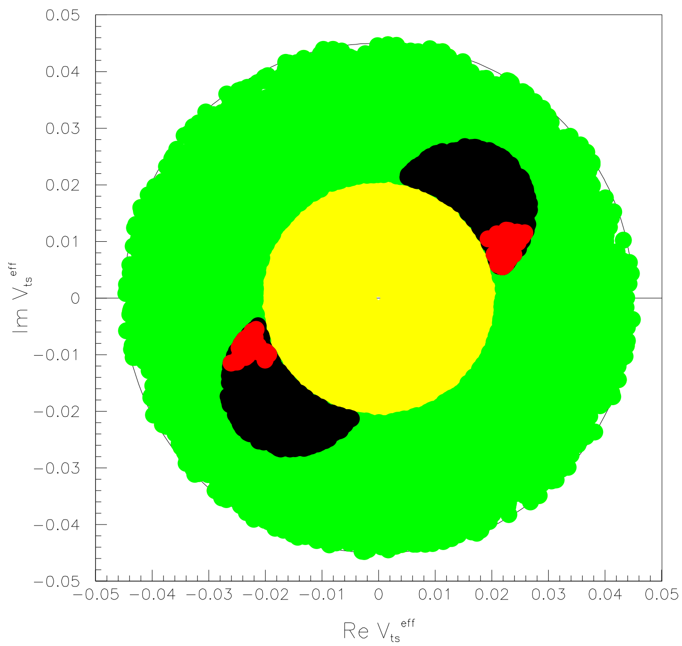

FIG. 2: Allowed parameters ($\mathrm{Re}V_{ts}^{\mathrm{eff}}, \mathrm{Im}V_{ts}^{\mathrm{eff}}$) under the B physics constraints and D0 dimuon asymmetry. The whole circle of the yellow (light grey) + green (grey) + black regions is allowed by $\mathrm{Br}(B \to X_s\gamma)$ only, the ring shape of the green (grey) + black regions allowed by $\mathrm{Br}(B \to X_s\gamma)$ and ΔM_s. The black regions allowed by both constraints of $\mathrm{Br}(B \to X_s\gamma)$ and ΔM_s, and satisfies A_{sl}^b measured by D0. The red (dark grey) dots denote points additionally allowed by CP asymmetries in $B \to \phi K$ decays. The confidence level is at 95 % C.L..

C. CP asymmetries in $B \to \phi K$ decays

The $b \to s\bar{s}s$ transition responsible for the $B \to \phi K$ decays arises at one-loop level in the SM, where the gluon penguin contribution dominates. Since V_{ts}^{SM} involves no complex phase in the leading order in the SM, the weak phase $\sin 2\beta$ measured in $B \to \phi K$ decays should agree with that of $B \to J/\psi K$ decays and the direct CP asymmetry of $B \to \phi K$ decays should vanish up to small pollution.

The decay amplitude of $B \to \phi K$ decays with anomalous top couplings are given in Ref. [6]. We define the parameter λ as

$$\lambda = \sqrt{\frac{M_{12}^{d\,*}}{M_{12}^d}}\frac{\bar{A}}{A}, \tag{20}$$

where $A = \mathcal{A}(B^0 \to \phi K^0)$, $\bar{A} = \mathcal{A}(\bar{B}^0 \to \phi \bar{K}^0)$ and M_{12}^d is given in Eq. (18). The time-dependent CP asymmetry in $B \to \phi K$ decays are written in terms of λ as

$$\begin{aligned} a_{\phi K}(t) &\equiv \frac{\Gamma(\bar{B}^0(t) \to \phi \bar{K}^0) - \Gamma(B^0(t) \to \phi K^0)}{\Gamma(\bar{B}^0(t) \to \phi \bar{K}^0) + \Gamma(B^0(t) \to \phi K^0)}, \\ &= S_{\phi K} \sin \Delta m_B t - C_{\phi K} \cos \Delta m_B t, \end{aligned} \tag{21}$$

where the coefficients

$$\begin{aligned} S_{\phi K} &= \frac{2\mathrm{Im}\lambda}{1+|\lambda|^2}, \\ C_{\phi K} &= \frac{1-|\lambda|^2}{1+|\lambda|^2} = -A_{\phi K}, \end{aligned} \tag{22}$$

are measured in the Belle and BaBar, of which average values are $-\eta S_{\phi K} = 0.44^{+0.17}_{-0.18}$, and $C_{\phi K} = -0.23 \pm 0.15$, [21].

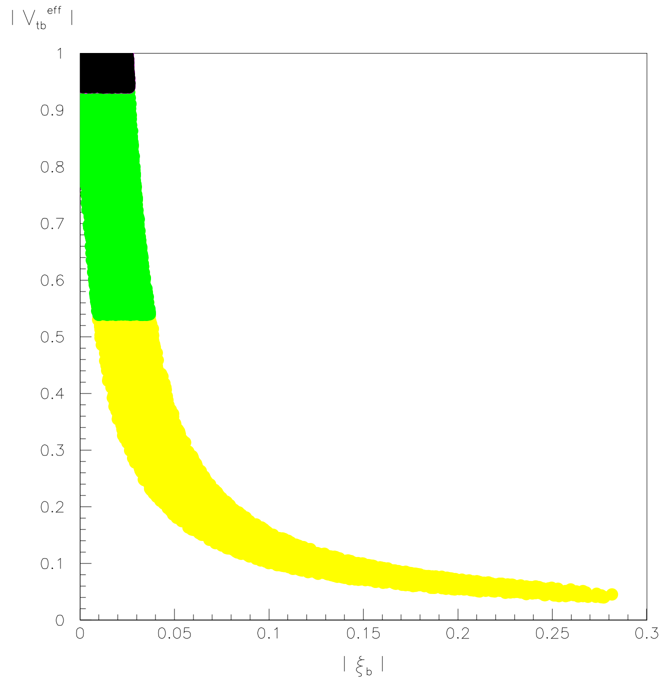

FIG. 3: Allowed parameters $(|\xi_b|, |V_{tb}^{\rm eff}|)$ under the B physics constraints and D0 dimuon asymmetry. The whole band of the black + green (grey) + yellow (light grey) regions is allowed by Br$(B \to X_s\gamma)$ only. The black + green (grey) regions are allowed by Br$(B \to X_s\gamma)$, ΔM_s and ΔM_d. The black region is allowed by all constraints of Br$(B \to X_s\gamma)$, ΔM_s, ΔM_d, $S_{\phi K}$, $C_{\phi K}$, and satisfies A_{sl}^b measured by D0. The confidence level is at 95 % C.L..

IV. RESULTS

First we consider the nonzero anomalous tsW couplings. The $B_d - \bar{B}_d$ mixing is not affected in this case and we get constraints on the tsW couplings from the $B \to X_s\gamma$ decay, ΔM_s, and CP asymmetry in $B \to \phi K$ decays. Figure 1 shows the allowed parameters of $|\xi_s|$ and $|V_{ts}^{\rm eff}|$ at 95 % C.L.. In the $B \to X_s\gamma$ decays of Eq. (17), the contribution of the right-handed couplings involves the enhancement factor m_t/m_b and leads to substantial change of the amplitude. Since the measurements of Br$(B \to X_s\gamma)$ agree with the SM predictions, the substantial change of the amplitude due to ξ_s should be compensated by a large shift of $V_{ts}^{\rm eff}$ as we can see in Fig. 1. On the other hand, the contribution of ξ_s to M_{12}^s does not involve such an enhancement factor and M_{12}^s is governed merely by $V_{ts}^{\rm eff}$. The like-sign dimuon charge asymmetry is affected through M_{12}^s. Thus we find that the deviation of A_{sl}^b from the SM value leads to the deviation of $V_{ts}^{\rm eff}$ and also the nonzero ξ_s. Finally these values satisfy the CP asymmetry in $B \to \phi K$ decays in most region. We have allowed values of $V_{ts}^{\rm eff}$ and ξ_s

$$0.01 < |\xi_s| < 0.03, \quad 0.022 < |V_{ts}^{\rm eff}| < 0.029, \tag{23}$$

from all experimental constraints. We find our results show sizable deviation from the value of $|V_{ts}| = 0.0403$ from the global fit of the unitary triangle in the SM [10]. Note that this result does not mean the violation of the CKM unitarity but that an "effective" parameter $V_{ts}^{\rm eff}$ extracted from $B_s - \bar{B}_s$ mixing looks different from the SM value.

We show the allowed region of the complex parameter $V_{ts}^{\rm eff}$ at 95 % C.L. in Fig. 2. The sizable phase is predicted, $14^o < \theta_{ts}^{\rm eff} < 22^o$ and $194^o < \theta_{ts}^{\rm eff} < 202^o$ from the measured A_{sl}^b value in this plot, while it is very small $\sim 2^o$ in the SM. Note that this phase is essential to explain the dimuon charge asymmetry. Since new effects on Γ_{12}^q are ignored in this work, our CP phase $\phi_s = -2\theta_{ts}^{\rm eff}$ comes only from the $B_s - \bar{B}_s$ mixing. Our results are consistent with the 2010 results $\phi_s(\text{CDF}) = (-29^{+44}_{-49})^o$ [27] and $\phi_s(\text{D0}) = (-44^{+59}_{-51})^o$ [28] from $B_s \to J/\psi\phi$ decays and also consistent with the recent best-fit value $\phi_s = (-52^{+32}_{-25})^o$ at 2-σ level [29]. Such agreements are understood by that all observed CP asymmetries at present in the B_s system can be explained by the indirect CP violation through modified $B_s - \bar{B}_s$ mixing. In our case, the modified B_s mixing is due to $V_{ts}^{\rm eff}$.

Considering the anomalous tbW couplings to explain A_{sl}^b, we have constraints from $B \to X_s\gamma$ decay, ΔM_s, ΔM_b,

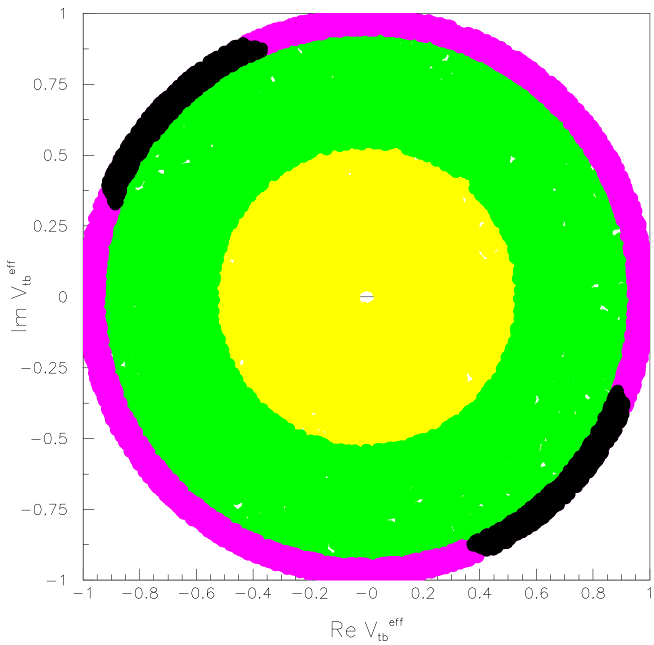

FIG. 4: Allowed parameters $(\mathrm{Re}V_{tb}^{\rm eff}, \mathrm{Im}V_{tb}^{\rm eff})$ constraints and D0 dimuon asymmetry. The whole circle of the yellow (light grey) + green (grey) + magenta (dark grey) + black regions is allowed by $\mathrm{Br}(B \to X_s\gamma)$ only. The thick ring of the green (grey) + magenta (dark grey) + black regions allowed by $\mathrm{Br}(B \to X_s\gamma)$ and ΔM_s, and the thin ring of the magenta (dark grey) + black regions allowed by $\mathrm{Br}(B \to X_s\gamma)$, ΔM_s, and ΔM_d. The black region is allowed by all constraints of $\mathrm{Br}(B \to X_s\gamma)$, ΔM_s, ΔM_d, $S_{\phi K}$, $C_{\phi K}$, and satisfies A_{sl}^b measured by D0. The confidence level is at 95 % C.L..

and the CP asymmetry in $B \to \phi K$ decays. In Fig. 3, we show the allowed parameters of $|\xi_b|$ and $|V_{tb}^{\rm eff}|$ at 95 % C.L.. In this case, the SM value of $|V_{tb}^{\rm eff}| = 1$ is still consistent with the dimuon charge asymmetry. Instead we require new phase of $V_{tb}^{\rm eff}$ to explain the A_{sl}^b as shown Fig. 4 although V_{tb} is real in the SM. We used the SM value of the CP violating phase $\phi_d^{\rm SM} = -0.091^{+0.026}_{-0.038}$ [25]. Figure 4 allows the phase angle $-66^o < \theta_{tb} < -21^o$ and $114^o < \theta_{tb} < 159^o$ at 95 % C.L.. However, the CP phase of B_d system is precisely measured in $B \to J/\psi K_s$ and the recent world average value is given by [21] $\sin 2\beta = 0.676 \pm 0.020$, which agrees with the SM predictions very well. Then the large additional phase of V_{tb} is not consistent with the measured $\sin 2\beta$. Such disagreement implies that it is hard to explain the dimuon charge asymmetry and the $B \to J/\psi K$ decay simultaneously only with the modification of $V_{tb}^{\rm eff}$. Thus we conclude that the dimuon charge asymmetry favours the anomalous tsW couplings rather than tbW couplings.

Since the anomalous tsW couplings contribute to M_{12}^s and not to M_{12}^d, only a_{sl}^s is shifted as ξ_s varies. Meanwhile, both M_{12}^s and M_{12}^d are affected by the anomalous tbW couplings and also both a_{sl}^s and a_{sl}^b are modified as ξ_b varies. We show the variation of a_{sl}^s and a_{sl}^b in Fig. 5 with the allowed parameter sets of $(\xi_s, V_{ts}^{\rm eff})$ and $(\xi_b, V_{tb}^{\rm eff})$ given in Fig. $1-4$.

V. CONCLUDING REMARKS

We have studied the effects of the anomalous tsW and tbW couplings to explain the recently measured deviation of like-sign dimuon charge asymmetry at Tevatron. Our new complex couplings are able to explain the D0 dimuon charge asymmetry at 95 % C.L. under constraints from the precisely measured $\mathrm{Br}(B \to X_s\gamma)$, ΔM_d, ΔM_s, $S_{\phi K}$, and $C_{\phi K}$ data. However the additional phase of $V_{tb}^{\rm eff}$ is not consistent with the CP violation in $B \to J/\psi K$ decay, while the anomalous tsW couplings agree with that in $B \to J/\psi\phi$ decays at 2-σ level. We conclude that the dimuon charge asymmetry favours a new top couplings in $B_s - \bar{B}_s$ mixing than in $B_d - \bar{B}_d$ mixing, and show that the anomalous tsW couplings satisfies constraints of B physics.

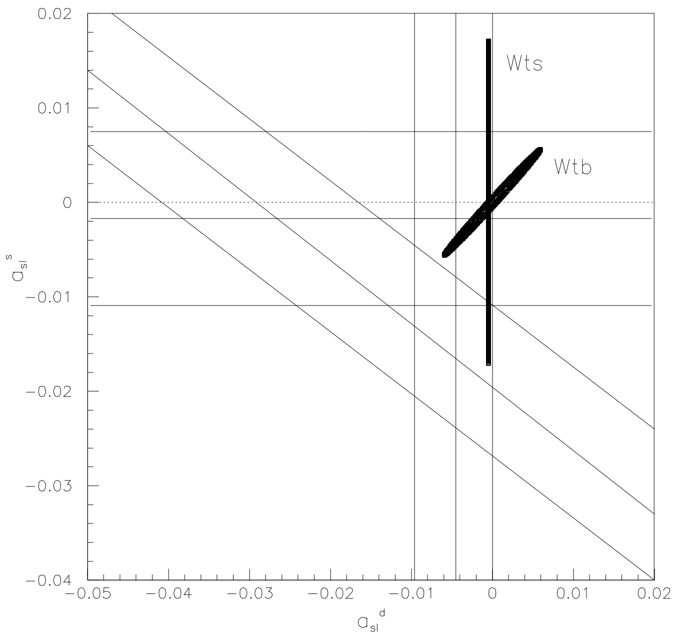

FIG. 5: The thick black lines are our predictions of a_{sl}^d and a_{sl}^s varying the anomalous tbW and tsW couplings with the measurements of A_{sl}^b (inclined band) by D0 [1], a_{sl}^d (vertical band) at B factory [21] and a_{sl}^s (horizontal band) by D0 [26]. The crossing point of thick lines denotes the SM prediction. The $1-\sigma$ error bands are shown.

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[1] V.M. Abazov *et al.*, D0 collaboration, Phys. Rev. D **84**, 052007 (2011); V.M. Abazov *et al.*, D0 collaboration, Phys. Rev. Lett. **105**, 081801 (2010); V.M. Abazov *et al.*, D0 collaboration, Phys. Rev. D **82**, 032001 (2010).

[2] R. Fleischer and R. Knegjens, arXiv:1109.5115 [hep-ph]; H. Ishimori, Y. Kajiyama, Y. Shimizu, and M. Tanimoto, arXiv:1103.5705 [hep-ph]; A. Datta, M. Duraisamy, and S. Khalil, Phys. Rev. D **83**, 094501 (2011); J. E. Kim, M.-S. Seo, and S. Shin, Phys. Rev. D **83**, 036003 (2011); A.K. Alok, S. Baek, and D. London, JHEP **1107**, 111 (2011); X.-G. He, B. Ren, P.-C. Xie, Phys. Lett. B **698**, 231 (2011); J.-P. Lee, Phys. Rev. D **82**, 096009 (2010); M. Trott, M.B. Wise, JHEP **1011**, 157 (2010); S. Oh and J. Tandean, Phys. Lett. B **697**, 41 (2011); K. Blum, Y. Hochberg, and Y. Nir, JHEP **1009**, 035 (2010); S.F. King, JHEP **1009**, 114 (2010); J. Kubo and A. Lenz, Phys. Rev. D **82**, 075001 (2010); Y. Bai and A. Nelson, Phys. Rev. D **82**, 114027 (2010); P. Ko and J.-h. Park, Phys. Rev. D **82**, 117701 (2010); J.K. Parry, Phys. Lett. B **694**, 363 (2011); C.-H. Chen, C.-Q. Geng, and W. Wang, JHEP **1011**, 089 (2010); D. Choudhury and D.K. Ghosh, JHEP **1102**, 033 (2011); N.G. Deshpande, X.-G. He, and G. Valencia, Phys. Rev. D **82**, 056013 (2010); C.W. Bauer and N.D. Dunn, Phys. Lett. B **696**, 362 (2011); Z. Ligeti, M. Papucci, G. Perez, and J. Zupan, Phys. Rev. Lett. **105**, 131601 (2010); B.A. Dobrescu, P.J. Fox, and A. Martin, Phys. Rev. Lett. **105**, 041801 (2010); A. Dighe, A. Kundu, and S. Nandi, Phys. Rev. D **82**, 031502 (2010).

[3] V. Barger, W.-Y. Keung, and C.-T. Yu, Phys. Rev. D **81**, 113009 (2010); D. London and D. Wyler, Phys. Lett. B **232**, 503 (1989); T. Kurimoto, A. Tomita, and S. Wakaizumi, Phys. Lett. B **381**, 470 (1996); J. Chay, K. Y. Lee, and S.-h. Nam, Phys. Rev. D **61**, 035002 (1999); J. H. Jang, K. Y. Lee, S. C. Park, and H. S. Song, Phys. Rev. D **66**, 055006 (2002).

[4] R. D. Peccei and X. Zhang, Nucl. Phys. **B337**, 269 (1990); R. D. Peccei, S. Peris and X. Zhang, Nucl. Phys. **B349**, 305

(1991).
[5] J. P. Lee and K. Y. Lee, Phys. Rev. D **78**, 056004 (2008).
[6] J. P. Lee and K. Y. Lee, Euro. Phys. J. C **29**, 373 (2003).
[7] W. Bernreuther, P. Gonzalez and M. Wiebusch, Euro. Phys. J. C **60**, 197 (2009); J.A. Aguilar-Saavedra, Nucl. Phys. **B804**, 160 (2008); B. Grzadkowski and M. Misiak, Phys. Rev. D **78**, 077501 (2008); M.M. Najafabadi, JHEP **0803**, 024 (2008); J.A. Aguilar-Saabedra, J. Carvalho, N.F. Castro, F. Veloso, and A. Onofre, Euro. Phys. J. C **50**, 519 (2007); K. Y. Lee, Phys. Lett. B **632**, 99 (2006); J. P. Lee, Phys. Rev. D **69**, 014017 (2004); K. Kolodziej, Phys. Lett. B **584**, 89 (2004); K. Y. Lee and W. Y. Song, Phys. Rev. D **66**, 057901 (2002); K. Y. Lee and W. Y. Song, Nucl. Phys. Proc. Suppl. **111**, 288 (2002); S. Atag, O. Cakir, and B. Dilec, Phys. Lett. B **522**, 76 (2001); E. Boos, M. Dubinin, M. Sachwitz, and H.J. Schreiber, Euro. Phys. J. C **16**, 269 (2000); E. Boos, A. Pukhov, M. Sachwitz, and H.J. Schreiber, Phys. Lett. B **404**, 119 (1997); F. Larios, M.A. Perez, and C.P. Yuan, Phys. Lett. B **457**, 334 (1999).
[8] F. Abe *et al.*, CDF Collaboration, Phys. Rev. Lett. **73**, 225 (1994); Phys. Rev. Lett. **74**, 2626 (1995); Phys. Rev. Lett. **80**, 2767 (1998); Phys. Rev. Lett. **80**, 2773 (1998); S. Abachi *et al.*, D0 Collaboration, Phys. Rev. Lett. **74**, 2632 (1995); Phys. Rev. Lett. **79**, 1197 (1997); Phys. Rev. Lett. **79**, 1203 (1997); D. Abbott *et al.*, D0 Collaboration, Phys. Rev. Lett. **80**, 2063 (1998); Phys. Rev. Lett. **82**, 271 (1999); Phys. Rev. D **58**, 052001 (1998); Phys. Rev. D **60**, 052001 (1999).
[9] Y. Grossman, Y. Nir, and G. Raz, Phys. Rev. Lett. **97**, 151801 (2006).
[10] C. Amsler *et al.* (Particle Data Group), Phys. Lett. B **667**, 1 (2008), and 2009 partial update for the 2010 edition.
[11] M. Beneke *et al.*, hep-ph/0003033.
[12] M. Beneke, G. Buchalla, and I. Dunietz, Phys. Rev. D **54**, 4419 (1996).
[13] W. Bernreuther, hep-ph/0805.1333.
[14] A. Abulencia *et al.*, CDF collaboration, Phys. Rev. Lett. **97**, 242003 (2006.)
[15] D0 collaboration, D0 Note 5618-CONF v1.2..
[16] G. Buchalla, A.J. Buras, and M.E. Lautenbacher, Rev. Mod. Phys. **68**, 1125 (1996); A.J. Buras, hep-ph/9806471.
[17] T. Inami and C.S. Lim, Prog. Theo. Phys. **65**, 297 (1981).
[18] P. Cho and M. Misiak, Phys. Rev. D **49**, 5894 (1994).
[19] A.L. Kagan and M. Neubert, Euro. Phys. J. C **7**, 5 (1999).
[20] M. Misiak and M. Steinhauser, Nucl. Phys. **B764**, 62 (2007); M. Misiak *et al.*, Phys. Rev. Lett. **98**, 022002 (2007).
[21] D. Asner *et al.*, Heavy Flavor Averaging Group (HFAG), arXiv:1010.1589 [hep-ex].
[22] V. M. Abazov *et al.*, D0 Collaboration, Phys. Rev. D **76**, 057101 (2007); T. Aaltonen *at al.*, CDF Collaboration, arXiv:0712.2397 [hep-ex]; V. M. Abazov *et al.*, D0 Collaboration, arXiv:0802.2255 [hep-ex].
[23] U. Nierste, Int. J. Mod. Phys. A **22**, 5986 (2008); P. Ball, hep-ph/0703214; A. Lenz, Phys. Rev. D **76**, 065006 (2007); M. Blanke, A. J. Buras, S. Recksiegel and C. Tarantino, arXiv:0805.4393 [hep-ph]; J. Hisano and Y. Shimizu, arXiv:0805.3327 [hep-ph]; P. Ko, Nucl. Phys. Proc. Suppl. **163**, 185 (2007); J. K. Parry and H. h. Zhang, arXiv:0710.5443 [hep-ph]; F. J. Botella, G. C. Branco and M. Nebot, arXiv:0805.3995 [hep-ph]; J. A. Aguilar-Saavedra, F. J. Botella, G. C. Branco and M. Nebot, Nucl. Phys. **B706**, 204 (2005).
[24] A. J. Buras, M. Jamin and P. H. Weisz, Nucl. Phys. **B347**, 491 (1990).
[25] A. Lenz and U. Nierste, JHEP **06**, 072 (2007).
[26] V.M. Abazov *et al.*, D0 collaboration, Phys. Rev. D **82**, 012003 (2010);
[27] CDF collaboration, CDF note 9458, 7 August 2008; T. Aaltonen *et al.*, CDF collaboration, Phys. Rev. Lett. **100**, 161802 (2008); Phys. Rev. Lett. **100**, 121803 (2008).
[28] V.M. Abazov *et al.*, D0 collaboration, Phys. Rev. Lett. **101**, 241801 (2008); Phys. Rev. Lett. **98**, 121801 (2007).
[29] A. Lenz and U. Nierste, arXiv:1102.4274 [hep-ph].